3p refs

N63 23795

code none

Sealing manned spacecraft

No more important problem confronts the engineer; a single minor defect can drain the entire air supply of a spacecraft on a long-duration mission

[5]

~~By~~ OTTO F. TROUT JR. N.Y., Amer. Inst. of Aeron. and Astronautics, Aug. 1963
NASA, Langley Research Center, Langley Station, Va.

Reprint

Space stations and manned interplanetary spacecraft impose stringent requirements for sealing the living environment and onboard equipment during all phases of operation in outer space, for extended periods of time, and with minimum maintenance. Leakage rates encountered on short-duration vehicles such as Mercury cannot be tolerated in extended space missions. The Mercury spacecraft has had a leakage rate of 2.4 lb per day in ground tests. This would amount to thousands of pounds per year scaled to vehicles for extended space missions.

Four main areas in spacecraft require sealing:

1. Environmental containers, which includes structural joints, air locks, docking transfer ports, erectable joints, and observation ports.
2. Propulsion systems, which includes lines, tankage, valves, bladders, and fuel transfer ports.
3. Hydraulic, pneumatic, mechanical and electrical feed-throughs for operation of equipment on the outside of the station.
4. Punctures.

The requirements imposed by extended outer-space operation have made it necessary to determine the seal problem areas, to establish an understanding of seal mechanisms and theory, and to examine the critical parameters required to achieve reliable sealing of large lightweight structures.

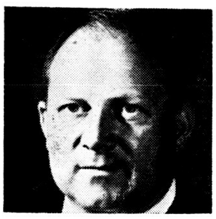
It is imperative that seals be examined in terms of configurations suitable for dynamic and static conditions and from the standpoint of suitable materials and the limitations imposed on them by exposure to hard vacuum, temperature variations, electromagnetic and particulate radiations, and structural loading. Methods of leak detection and methods of repair and self-sealing must be worked out for leaks caused by structural damage, micrometeoroid penetration, and normal everyday operations. Seal technology applicable to long-duration manned space travel must be examined with regard to available technology and the future research and development necessary to attain the required reliability.

Our discussion here of sealing problems will assume a hypothetical spacecraft consisting of a seamless metal pressure vessel, with all welds free of defects, and with only parts that must be operated in space to be sealed.

Seal Performance. The sketch on page 45 depicts a seal deformed between two surfaces. Leakage will occur by permeation of the contained fluid through the seal material (1). Permeation through most homogenous metals is almost negligible, but can be a finite problem through elastomeric and composite-type seal materials. Surface roughness (2) can be a serious source of leakage; it can be caused by poor surface finish or tool marks. Cracks (3), scratches (4) and other defects can also prevent effective sealing. Deterioration of seal material (5) from outgassing, aging, radiation damage, and permanent set or reaction with contained fluids will reduce seal effectiveness. Flange distortion (6) due to uneven loading, temperature distortion, and structural flexure will cause leakage.

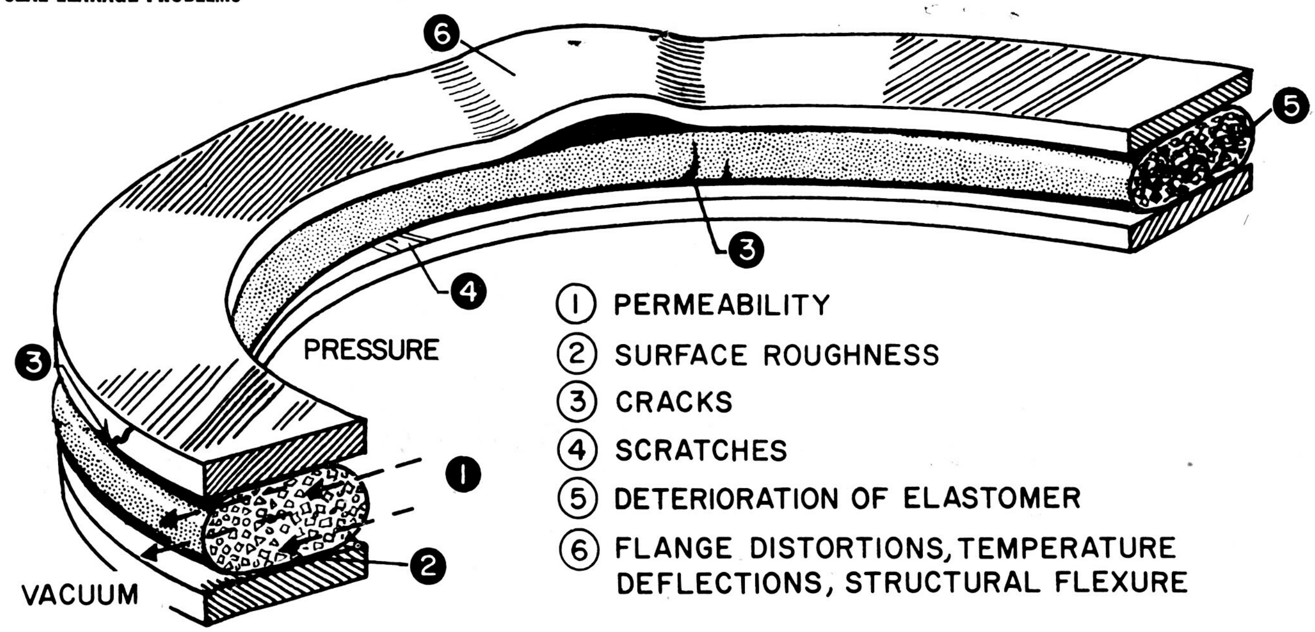
The relative importance of these seal imperfections to atmospheric containment aboard a manned space vehicle can be seen by comparing some calculated leakage rates of atmospheric pressure sealed against hard vacuum. The permeability leakage of 100 linear feet of neoprene O-ring will only amount to 0.02 lb of air per year. A single surface scratch or machine mark 0.01 by 0.01 in. will cause a leakage of 1200 lb of air per year. A fine crack in the metal 0.001 by 0.1 in. will cause a leakage of 1200 lb of air per year. A flange deflection due to uneven loading, temperature deflection, or structural deflection causing a gap 0.001 by 0.250 in. will cause a leakage of 3000 lb per year.

In brief, one minor defect can cause the dissipation of the entire air supply



OTTO F. TROUT JR. is an aerospace engineer in the Space Station Research Group engaged in study of advanced systems applicable to manned space vehicles. He joined the NASA Pilotless Aircraft Div. in 1950, participating in research, ground and flight testing of ramjet control and combustion systems, later working on development of high-temperature facilities. His transfer to the SSR Group last year led to a basic study of seal mechanisms and materials.

Repr~~inted~~ from ASTRONAUTICS AND AEROSPACE ENG~~INEERING~~, *Aug~~ust~~ 1963*



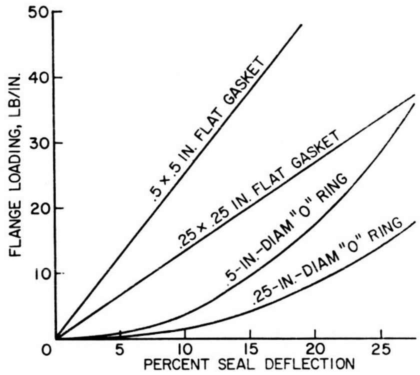
of a space vehicle during its mission. The elimination of defects obviously constitutes a major problem in forming effective seals.

An important parameter to be considered is the seating stress, the pressure necessary to force the seal material to flow into the surface irregularities of the flanges. Seals which do not flow into surface irregularities may sometimes be suitable for containing liquids because of their viscosity, but will not prevent gases from flowing into a vacuum. Leakage rate as a function surface roughness can be calculated with reasonable accuracy. The table on page 46 shows minimum seating stress necessary to form a good vacuum seal between infinitely rigid flanges, of several materials, having a relatively good surface finish (less than a root mean square of 30 microinch).

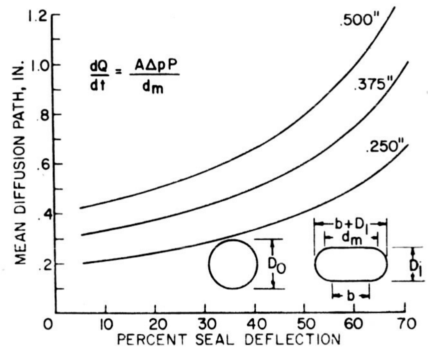
Elastomeric materials require a seating stress approximately 2 1/2 to 3 orders of magnitude less than metals, whereas nonelastomeric polymeric materials, such as Teflon, require seating stresses approximately an order of magnitude higher than elastomers. Minimum seating pressure of any seal, therefore, will be a function of seating stress times the area in contact with the flange. In the table, this seating load is given for a 1/4-in.-diam O-ring.

For lightweight structures, metallic seals are not practical except for diameters of less than a few inches. Because of inelasticity, metallic seals do not perform satisfactorily during thermal cycling and structural flexure.

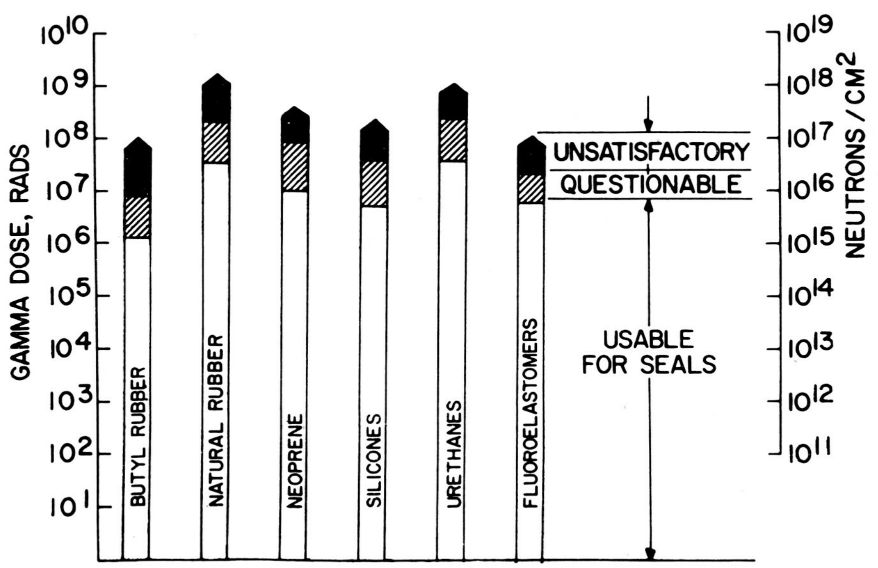
FLANGE LOADING AGAINST DEFLECTION
60-Durometer Elastomer



DIFFUSION PATH VS. DEFLECTION



RELATIVE RADIATION DAMAGE TO ELASTOMERIC MATERIALS



MINIMUM SEAL SEATING STRESS

Material	Seating stress, lb/sq in.	Seating load[a] of 1/4-in.-diam O-ring, lb/in.
Rubber	70	1.5
Teflon	1,000	21
Aluminum	16,000	325
Copper	36,000	435
Soft steel	55,000	1,130
Stainless steel	75,000	1,500

[a] Values from Ref. 1.

AIR-LEAK RATES OF ELASTOMERIC O RINGS[a]

Material	Permeability, cc-cm²-cm-atm-sec	Air-leak rate at 100 C, cc/in./yr	
		Calculated	Experimental
Vinton A	8.8×10^{-8}	0.36	0.44
Neoprene	7.0×10^{-8}	0.29	0.29
Silicone	450×10^{-8}	18.40	3.60
Butyl rubber	3.2×10^{-8}	0.13	0.37

[a] Values from Ref. 2.

Elastomers, on the other hand, have the advantages of low flange loading and high flexibility, but have the disadvantages of high permeability and low resistance to ultraviolet, particulate, and electromagnetic radiation. Then, too, they are useful only over a very narrow temperature range.

Recently, flange loadings as a function of deflection have been calculated by use of elastic body theory for some of the more common seal configurations for various durometer hardnesses. For a 60-durometer elastomer, deflections of 5% will generally form a vacuum seal with either a flat gasket or an O-ring configuration on a surface finish less than a root mean square of 32 mocroinches, as indicated in the graph on page 45. However, deflections of 10-15% are required to approach 100% reliability. Increased compressive load results in decreased leakage, because the seal material fills the surface imperfections.

Unless the seal material and containing flanges are free of defects, then, and unless the minimum seating stress is maintained along the entire length of the seals during all static and dynamic conditions of spacecraft operation, effective sealing will not be possible for extended missions.

Permeability and Materials. The amount of air which will permeate a seal is directly a function of time, cross-sectional area, differential pressure, and permeability coefficient and is inversely proportional to the mean permeation path. The performance of seals can thus be predicted, and has been calculated for several shapes. As an example, the calculated mean permeation path for several sizes of O-rings is given in the middle right graph on page 45. The table top right presents experimental measurements of air leakage through elastomeric O-rings. These were obtained by National Research Corp. for several elastomeric materials used to seal atmospheric pressure against pressures up to 10^{-9}-mm Hg. They show fair agreement with calculated leakage.

Elastomeric polymers of low unsaturation and free of plasticizers, softeners, antioxidents, and fillers are most suitable for seals in hard vacuum. Evaporation of these additives may increase the permeability of seal materials by orders of magnitude. If these additives are to be omitted, only a narrow range of hardness for a given material is available.

The elastomeric polymers generally decompose in hard vacuum at a more rapidly increasing rate with temperature than do the more-heat-resistant polymers, such as Teflon, polyesters, polyamides, and polyvinyls. Additional research is needed to define the temperature stability of elastomers in hard vacuum, and development should be accelerated on elastomers suitable for use at higher temperatures.

The graph on page 45 shows the effect of radiation on various elastomeric materials. Absorbed radiation doses from 10^{6}-10^{7} rads begin to appreciably alter these materials and doses from 10^{7}-10^{9} rads generally render these materials useless.[3] The threshold damage to these materials is rather low compared with that to metals, but is still two or more orders of magnitude above the dose tolerable by man. Shielding of seals from radiation may be necessary when structure does not offer sufficient protection.

Deteriorating effect of ultraviolet on seal materials can best be tolerated by preventing direct exposure.

Meteoroid damage to seals does not appear to be a problem since the containing flanges will be considerably heavier than other structures. Sealing punctures in other parts of the structure is a major problem. Methods of effecting rapid repair of punctures need to be worked out, and further development of self-sealing devices is required.

Welding operations in space by such means as electron-beam, laser, resistance, and cold-pressure welding are theoretically feasible, but the economics of performing welding operations space needs further study. Welding as a means of sealing does not meet the criteria of reusability. It must be very carefully done to prevent defects.

Concluding Remarks. Study of sealing problems in extended space missions has shown that acceptable leakage rates for atmospheric confinement is possible with presently available seal materials providing—that the seal materials and flanges are free of defects, that the seating stress is maintained above the minimum acceptable value for vacuum use along the entire length of the seal during all dynamic and static conditions, and that the seals are protected against ultraviolet and electromagnetic radiation, high temperature, and micrometeoroid damage.

Accelerated research is needed in the field of elastomeric polymers to define the properties of available materials and to develop materials having greater high-temperature resistance, better aging and chemical resistance, and more resistance to permanent set in hard vacuum for extended periods of time.

Research in the area of self-sealing of punctures has just been started and needs acceleration.

It is of utmost importance that the engineer integrate seal design with all phases of design of the spacecraft. The mistake of designing complex openings in the structure, which are almost impossible to seal, and then looking for ways to seal them must be avoided if the sealing reliability necessary for extended spaceflight is to be achieved.

References

1. Anon.: "Space Station Connection and Seal Study," Contract NAS1-2164, Environmental Res. Associates (Randallstown, Md.), Oct. 1962.

2. Farkass, Imre, and Barry, Edward J., "Study of Sealants for Space Environment," NRC Res. Proj. No. 43-1-139 (Contract DA-19-020-506-ORD-5097), Nat. Res. Corp. (Cambridge, Mass.), 1960.

3. Mauri, R. E., "Seals and Gaskets," Space Materials Handbook, Claus G. Goetzel and John B. Singletary, eds., Contract AF 04(647)-673, Lockheed Missiles and Space Co., Jan. 1962, pp. 325-328. ●●